Measurement campaigns to investigate blowing snow and snow drift conditions at a high altitude site

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ABSTRACT: In order to make progress in avalanche research and to improve avalanche risk forecasting, at least two elements must be taken into account: the investigation of the spatial variability of snow depth and the study of meteorological conditions during blowing snow events in high alpine areas. Numerical models (NEMO, Sytron 2 & 3) have been developed to simulate the redistribution of the snow pack during those events. More recently, we tested the ability of a meso-scale atmospheric model to explicitly simulate wind-induced snow transport in alpine terrain.
The characteristics and mechanisms of blowing snow events must be verified and the results of the models can then be validated through the use of in-situ measurements.
Over the last two years we have successfully performed intensive measurement campaigns at our experimental site (Col du Lac Blanc, French Alps, 2,700 m asl). We followed the evolution of snow depth over an area of 2×1 km² around our experimental site using data from a Terrestrial Laser Scanner.
In addition, in-situ measurements were collected during blowing snow events:

- Vertical profile of snow fluxes using mechanical traps and Snow Particles Counters (SPC),
- Vertical profile of wind velocity, air temperature and relative humidity on a meteorological mast,
- Wind speed and air temperature at three automatic weather stations.

These measurements represent a whole dataset suitable for the evaluation of models that simulate wind-induced snow transport in alpine terrain.
We present in this paper the first results of this in-situ study.

KEYWORDS : blowing snow modeling, in-situ measurements.

1. INTRODUCTION

While snow transport by the wind has a great influence on the snow depth distribution and on the evolution of the snow pack stability, we must take into consideration blowing snow events in order to improve the operational forecasting of avalanche risk (Guyomarc'h et al., 2009). The Snow Study Centre (specialized research centre of Météo-France) and IRSTEA (previously Cemagref) have been working for several years towards upgrading the knowledge on blowing snow and its numerical modeling in alpine areas. After numerous observations and measurements at an experimental site, some numerical models: NEMO (Naaim Bouvet et al., 1998), Sytron 2 & 3 (Durand et al., 2004, 2005) have been developed to simulate the occurrence of such phenomena and the redistribution of the snow pack during those events. More recently, we tested the ability of a meso-scale atmospheric model to explicitly simulate wind-induced snow transport in alpine terrain (Vionnet et al., 2011).

Other recent studies focus on fine scale process during blowing snow events (Naaim Bouvet et al., 2010) and on the modeling of blowing snow occurrence using the Crocus snow pack model (Vionnet et al., 2012). The study presented here takes place in this context and takes advantage of a high-altitude experimental site to investigate meteorological conditions during blowing snow events and their consequances on the snow pack.

2. EXPERIMENTAL SITE

In order to conduct observations on meteorological conditions of blowing snow events associated with snow features and wind velocity, we have used a high altitude site in the French Alps for around 20 years. This experimental site (Col du Lac Blanc) is situated at 2,700 m high close to the Alpe d'Huez ski resort. This pass could be considered as a "natural wind tunnel" due to its surrounding topography (figure 1).

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Figure 1: View to South-East of the experimental site.

Figure 2: View to North-East of the experimental site with the location of the 3 Automatic Weather Stations.

Since the beginning of the 1990's, blowing snow conditions were investigated by taking into account wind velocity thresholds according to snow grain characteristics at the snow surface. Three automatic weather stations (AWS) are located around the pass (figure 2) and record meteorological data every 15 minutes: wind velocity (mean, max and mini), wind direction, air temperature and snow depth by using an ultrasonic sensor. Two heating precipitation gauges provide information regarding the amount of precipitation (snow water equivalent). However, as usual at this altitude, they suffer of high uncertainty in the measurements when strong winds occur and that is the case at the most part of the time. The site was also fitted with an ultrasonic anemometer and six cup anemometers mounted on a 10-m vertical mast.

In parallel, blowing snow fluxes are also measured with Snow Particle Counters (Sato et al., 1993). For the winter season of 2011 three SPC were deployed. One SPC was set up at a fixed position (4.4 m above the ground). Two others were set up near the snow pack surface. A fixed distance of one meter separates them. These two SPC could be raised manually when the height of snow increased. A snow depth sensor that measures the exact position of the SPC above the snow pack supplemented these devices.

3. DATA COLLECTED DURING MEASUREMENTS CAMPAIGNS.

For the purpose of this study, we organised intensive measurement campaigns over the last two winter seasons. Based on the forecasting of a blowing snow event (snow storm or blowing snow without concurrent precipitation) we defined a measurement protocol as following:

- before the event: we plan to perform a specific survey of snow height thanks to a terrestrial laser scanning (TLS) (figure 3) of the surrounding topography of the experimental site (Prokop, 2008 and some measurements of snow characteristics at the snow pack surface.

Figure 3: The Terrestrial Laser Scan at the northerly point of measurement.

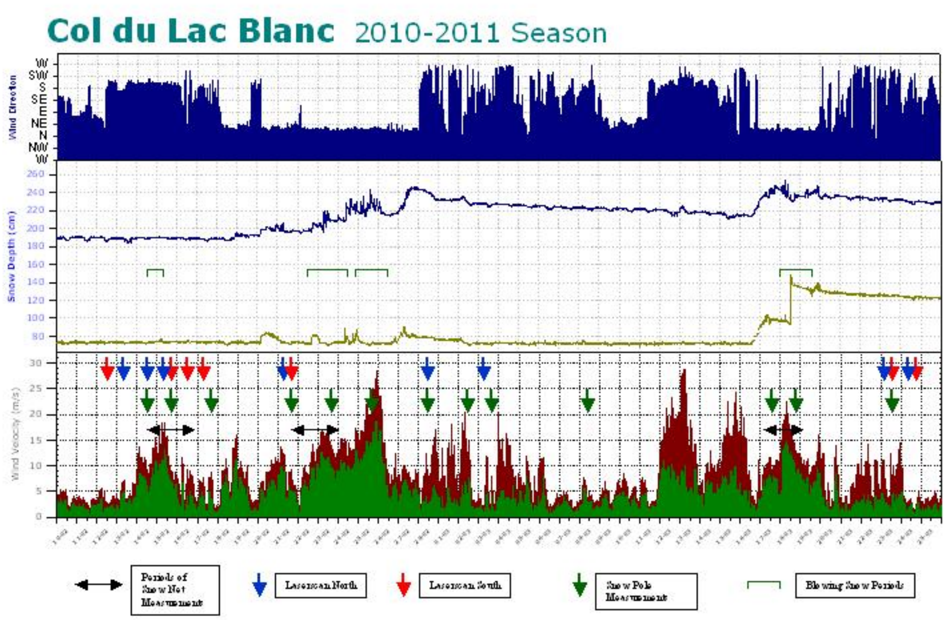
- During the event: measurements of the blowing snow flux are performed manually using snow nets along a vertical profile (figure 4) and at the same levels we record measurements at 1 min time step of a vertical profile of wind velocity and its direction, as well as automatic measurements of a three SPC profile (figure 5).

Figure 4: Vertical profile of snow nets used for the measurement of snow concentration in the atmosphere during a blowing snow event.

Figure 5: Vertical profile of wind velocity (on the left) and vertical profile of SPC (on the right).

- After the event, we perform again a terrestrial laser scanning of the surrounding topography and make measurements of snow features in accumulations.

Over the last two winter seasons, 6 blowing events have been investigated using the measurement protocol described above (figure 6).



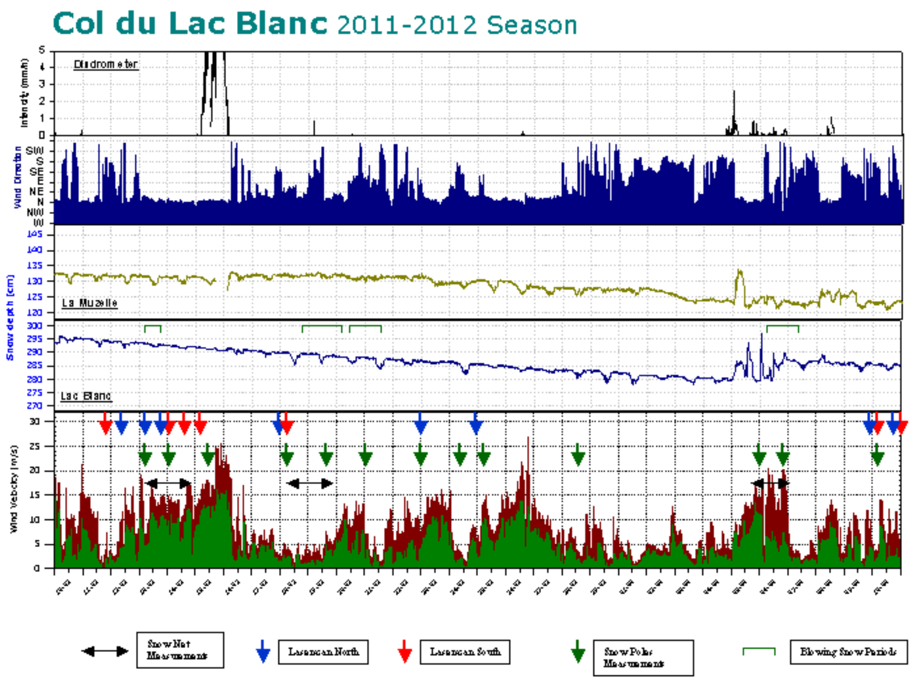


Figure 6: These 2 graphs show the periods of measurement campaigns over 2010-2011 and 2011-2012 winter seasons.

3. RESULTS.

3.1 Measurements of snow fluxes

Measuring snow flux is always a key point when we have to validate numerical models with in-situ data. This explains why we focused our observation on these measurements.

Figures 7 and 8 represent examples of vertical profiles of snow flux during blowing snow events respectively with and without concurrent snow falls. The three curves show different wind velocities during measurements and thus an increasing quantity of collected snow.

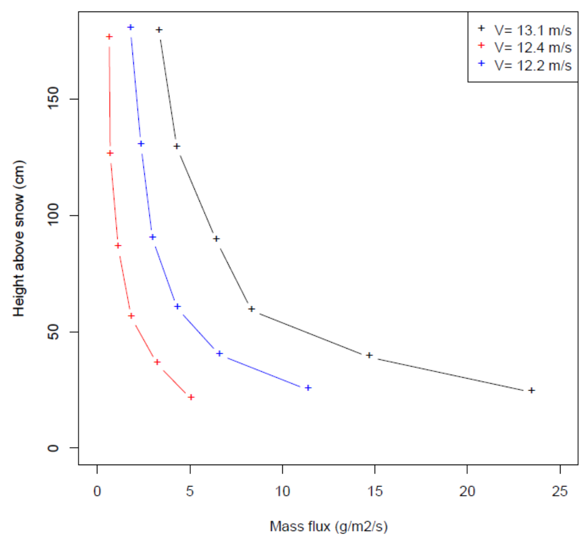


Figure 7: three examples of snow flux profiles with precipitation.

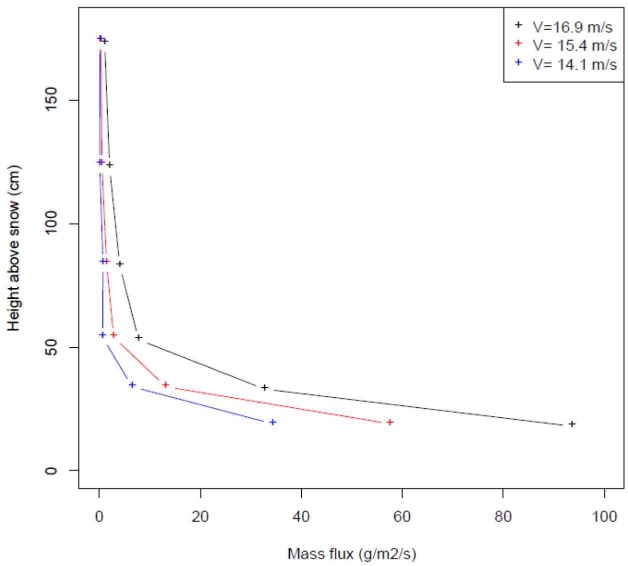


Figure 8: three examples of snow flux profiles without precipitation.

In winter season 2010-2011, we have compared profiles of blowing snow fluxes measured simultaneously on two poles separated from around 50 meters. Figure 9 shows the comparison for a blowing snow event during precipitations (16 profiles) and figure 10 without precipitation (4 profiles). The curve in red shows the mean values. The results show no bias between the two locations of measurements but a great variability when snow precipitations occur. We also noticed large differences near the snow surface when blowing snow event occurs without precipitation. The snow flux in saltation is greatly influenced by the micro-topography.

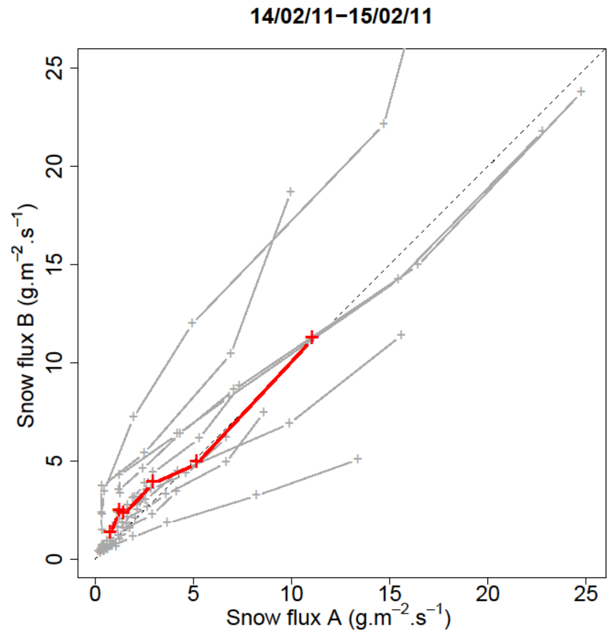


Figure 9: Comparison of snow flux measured at two positions separated from 50 m (A & B) during a blowing snow event with precipitations.

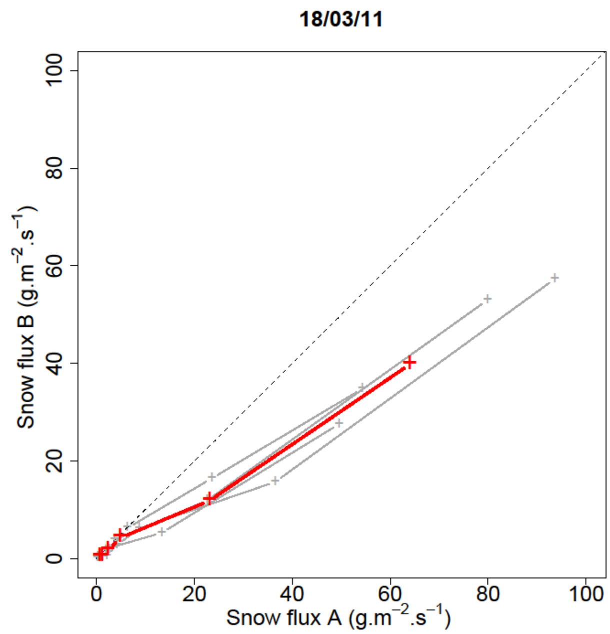


Figure 10: Same as figure 9 for a blowing snow event without precipitation

3.2 Comparison with SPC data

It appears interesting to compare now the data from the SPC and the measurements from “snow nets”. The figures below show a comparison between the fluxes measured with the three SPC and the snow net fluxes for a given period (a) and a comparison with the mean values of snow fluxes that we have interpolated at the height of the intermediate SPC for three blowing snow events. We can observe that the SPC always measure larger values of flux that our manual measurements. The mean value of the flux collected with the nets is around 35% of the SPC flux values. This is probably due to the collection efficiency of the snow nets which measure the snow flux depending of the material porosity. The comparisons shown here are calculated by using 41 measurements and show a similar behavior for the three blowing snow event. Assuming an efficiency of 35% for the snow nets we can get the adjusted profile shown on figure 11(a).

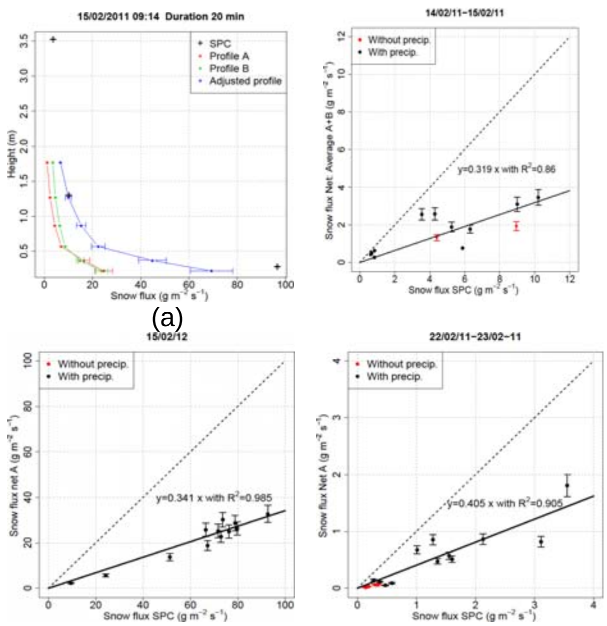


Figure 11 : comparison between the fluxes measured with the SPC and the snow net fluxes for a given period and for 3 blowing snow periods.

3.3 Measurements of vertical profile of wind

For each event in winter season 2010-2011, the wind velocity and direction are recorded with a time step of 1 min along a vertical profile near the snow surface (figure 12). The friction velocity is calculated for each measurement period by using a logarithm fit: $u = \frac{u_*}{\kappa}\ln(\frac{z}{z_0})$. The roughness length is variable depending on the wind direction as shown by: Naaim-Bouvet et al, 2010.

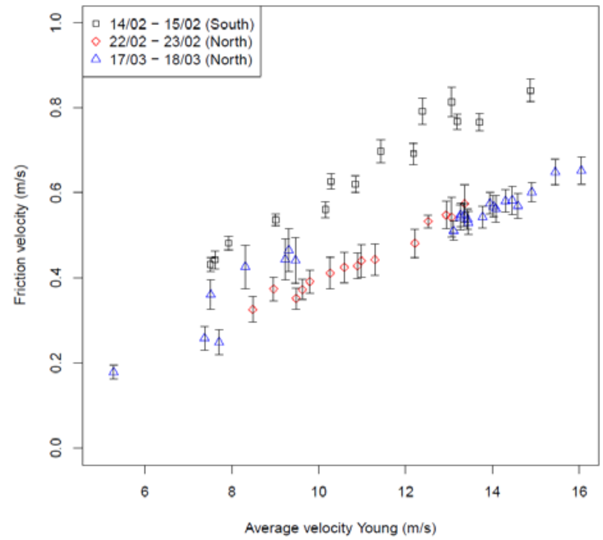


Figure 12: Average velocity of wind at 3.5 m versus the calculated friction velocity.

3.4 Comparison wind velocity/snow mass

The figure 13 shows an example of the blowing snow density versus the friction velocity. The wind velocity is interpolated at the height of the corresponding net.

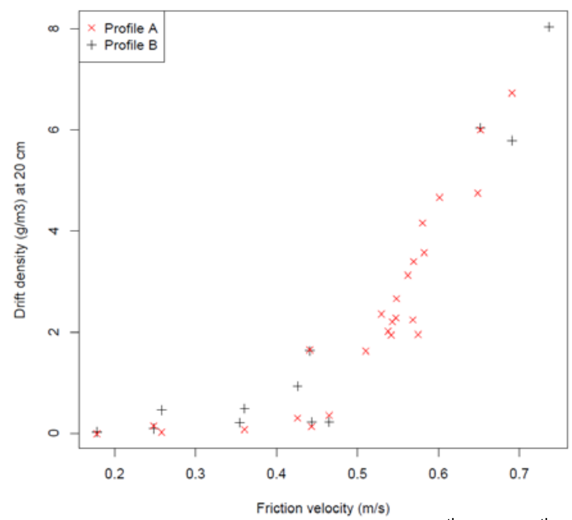


Figure 13: measurements performed on 17th and 18th of march 2011. The lower net is 20 cm above the snow surface.

3.5 Measurements of snow distribution

The applicability of terrestrial laser scanning to measure the depth of the snow cover has been shown by Prokop (2008). According to meteorological and snow pack conditions, and to the distance to the target, the measurements may provide accurate results (<10 cm at a distance less than 500 m).

For this study, we have used the difference between two images calculated from the TLS which deliver a snow map around our experimental site (figure 14). These maps will be very useful to verify the results of blowing snow models.

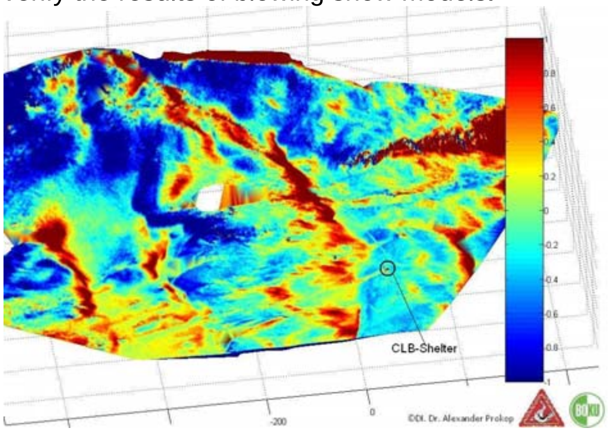


Figure 14: example of difference map of snow depth between 12 to 23 February 2011.

5. CONCLUSION

Meteorological recordings and in-situ measurements were combined to describe as fine as possible the conditions of blowing snow events and their consequences on the snow pack distribution and stability. Six blowing snow events were investigated during these observation campaigns. Measurements include blowing snow fluxes from snow nets and SPC, near-surface meteorological conditions and maps of snow depth difference using TLS. A detailed analysis of the collected profiles will be conducted.

All of the data collected represent a complete set that we can use for the assesment of models of snow transport by the wind in Alpine terrain and notably for new works on Meso-NH/Crocus modeling (Vionnet et al., 2011).

Lots of works remain to be done to better understand the mechanisms involved in blowing snow events at a fine scale.

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